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U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 104.

B. T. GALLOWAY, *Chief of Bureau.*

THE USE OF FELDSPATHIC ROCKS AS FERTILIZERS.

BY

ALLERTON S. CUSHMAN,

ASSISTANT DIRECTOR, OFFICE OF PUBLIC ROADS, AND COLLABORATOR, BUREAU OF PLANT INDUSTRY.

ISSUED MAY 27, 1907.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1907.

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[Continued on page 3 of cover.]

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., March 20, 1907.

Sir: I have the honor to transmit herewith a manuscript containing a review of all the work that has been done up to the present time in the investigation of the use of finely ground feldspathic rocks as fertilizers. There is a constantly growing demand for accurate information on this subject, and I therefore recommend that this manuscript be published as Bulletin No. 104 of the Bureau of Plant Industry.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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B. P. I.—275.

THE USE OF FELDSPATHIC ROCKS AS FERTILIZERS.

INTRODUCTION.

In view of the great demands that are being made upon the agricultural resources of the country, it is a matter of vital importance that consideration be given to the available supplies of elements which are necessary to sustain and maintain the quality and quantity of the crops. It is well known that there are three principal fertilizing materials: Nitrogen, phosphoric acid, and potash. The discovery of electrochemical and bacteriological processes for fixing the nitrogen of the air, thereby changing it into a form in which it can be used as a plant food, seems to remove all doubt as to the abundance of the supply of this important element for all time to come. An enormous geographical area of this continent is underlain with practically inexhaustible supplies of phosphatic rock, which, with the phosphates obtainable in waste bone, slaughterhouse tankage, fish scrap, and the basic slags from the iron industry, insure a limitless supply of phosphoric acid.

With regard to potash alone there has been reason to feel anxiety. Up to the present time no deposit or source of this necessary element in any of the forms in which it has been heretofore considered available as a plant food has been discovered or developed in this country. The mines of Stassfurt, Germany, furnish almost the entire supply of potash for fertilizer in the United States, exclusive of that which is used over and over by the processes of natural and green manuring. The potash salts, which up to this time have been exclusively used for fertilizing, consist of muriate, sulphate, nitrate, and carbonate, either in a crude or in a previously purified condition. Kainite is a trade name given to a crude product of the German mines, which contains about 13 per cent of actual potash, largely in the forms of sulphate and chlorid (muriate). The quantity and value of potash salt to be used as fertilizers imported in the fiscal years 1903, 1904, and 1905 are shown in the following table. The price of the potash unit has shown a tendency to increase each year.

TABLE I.—*Imports of potash salts for use as fertilizers.*[a]

Kind of fertilizer.	1903.		1904.		1905.	
	Weight.	Value.	Weight.	Value.	Weight.	Value.
	Pounds.	*Dollars.*	*Pounds.*	*Dollars.*	*Pounds.*	*Dollars.*
Crude carbonate	11,130,789	141,033	8,193,872	224,396	7,166,569	218,816
Crude muriate	172,888,780	2,630,457	161,503,735	2,428,480	202,366,601	3,241,152
Crude nitrate	11,946,685	320,082	16,727,175	433,626	14,512,306	386,098
Crude sulphate	45,156,964	782,082	47,592,131	833,954	54,577,670	958,305
Kainite	553,875,840	1,080,393	356,124,160	839,382	539,369,488	1,143,296
Total	794,949,058	4,954,047	590,141,073	4,759,838	817,992,634	5,947,667

[a] Compiled from data furnished by the Bureau of Statistics, U. S. Department of Agriculture.

All of the above salts of potash are readily soluble in water and therefore become quickly available as plant food when applied as fertilizers. On the other hand, the acids with which the potash is combined in these salts, especially in the cases of the sulphate and chlorid, are absorbed only in extremely minute quantities by growing plants. The natural consequence of this is that as the potash is taken away year after year the acid elements collect, in some cases to the great detriment of the soil.

Potash in some form is absolutely necessary to the successful growth of all crops, and is found in varying degrees in the ashes of wood and of vegetable growths of all kinds. This is illustrated in the following table, in which analyses of ashes of a number of vegetables are given. It must be remembered, however, that the amounts of this element found in the ashes of plants vary greatly under different conditions and that the sap of plants frequently absorbs much more of a given element than is actually necessary for its growth. The important point is that potash is an essential plant food of all crops, and particularly of those species which are starch builders.

TABLE II.—*Analyses of vegetable ash.*

Ash.	Phosphoric acid (P_2O_5).	Potash (K_2O).	Soda (Na_2O).	Ash.	Phosphoric acid (P_2O_5).	Potash (K_2O).	Soda (Na_2O).
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
Pea	36	40	1	Cabbage	16	48	4
Bean	30	44	1	Turnip	13	39	5
Potato	19	59	2	Artichoke	16	65	2
Parsnip	18	36	5	Tobacco	15	49	11
Carrot	12	36	13				

We can trace the source of potash in all its forms and wherever found to the igneous rocks which constituted the original crust of the earth. From the averages obtained from the analyses of a large number of crystalline rocks of common occurrence found in this coun-

try, Clarke[a] has made the following calculations of the relative abundance of various rock-forming minerals:

	Per cent.
Apatite (phosphate of lime)	0.6
Titanium minerals (oxids and silicates)	1.5
Quartz (silica)	12.5
Feldspar (silicates of aluminum, potash, soda, and lime)	59.0
Biotite mica (silicates of aluminum, magnesium, potash, etc.)	3.8
Hornblende and pyroxene (complex silicates)	16.8
Miscellaneous	5.8
Total	100.0

It is seen from this that probably the majority of all the original rocks contain more than 50 per cent of feldspar. There are, however, a great many different varieties of feldspar. The feldspars belong to a type of minerals known as silicates, in which aluminum and other elements, such as potash, soda, and lime, are combined with silica. Pure orthoclase feldspar is a silicate of aluminum and potash, which theoretically should contain 16.8 per cent of potash (K_2O). As a matter of fact it is extremely difficult to find an example of pure orthoclase, and in most of the feldspars, which occur in large deposits, the potash is to a greater or less extent replaced by soda or lime, or both. For this reason it is impossible to tell without a chemical analysis how much potash any given feldspar will contain. The granite rocks consist of feldspar, quartz, and a little mica in varying proportions; many of the other well-known rocks, such as the slates, sandstones, gneisses, and traps, also frequently contain more or less feldspar. Some of these rocks carry little or no potash, although many of them will run as high as 5 per cent; very few of them run higher than this.

A cubic foot of granite weighs about 170 pounds; on a 5 per cent basis, 8.5 pounds of this is potash. A quarry 100 feet square and 100 feet in depth of such rock would therefore contain 8,500,000 pounds of potash (K_2O). It is at once apparent that nature offers a limitless supply of raw material which only awaits an economical process to make the potash available.

In many localities there occur large dikes or deposits of more or less pure feldspars, which usually run higher in potash than the true granite rocks. These large deposits, which occur in a great many of the States, have been developed in Maine, Connecticut, Pennsylvania, New York, and Maryland, where they have been mined extensively and the feldspar ground to fine powder, principally for use in potteries. As has been said, pure orthoclase feldspar should contain 16.8 per cent of potash (K_2O), but none of these deposits will run on the average much more than 8 to 10 per cent. For pottery use it is essential that the spar should melt in a kiln fire to a clear white glass.

[a] Bul. 228, U. S. Geol. Survey, p. 20.

and it must therefore be almost entirely free from mica or iron-bearing minerals. For this reason there are large quantities of materials at every feldspar quarry which, though unfit for pottery use, would be valuable if any method were known of making potash available.

The question whether fine-ground feldspar can be used as a potash fertilizer has been a matter of controversy for many years. There is a large and widely scattered literature on the subject, an examination of which shows that the matter has been debated with much vigor and sometimes with prejudice and intolerance on both sides. It is easy to find the published records of a number of experiments, made by trained and thoroughly competent agriculturists, which tend to show that ground feldspar is an efficient potash fertilizer. On the other hand, a number of experiments seem to indicate that the potash is only slightly available, while others would appear to show that the ground rock is entirely useless. On account of the large interests involved in the settlement of this question it is not difficult to see why vigorous differences of opinion, and even unjust prejudice, should have arisen. When, however, trained investigators reach opposite conclusions, based upon experimental evidence, we are forced to the opinion that while ground feldspar may be a useful fertilizer under certain conditions it is not so under others.

It is the object of this bulletin to present and discuss as fully as possible all the evidence that can be obtained on both sides of this important question. The great demand for information on the subject which has arisen and the numerous misstatements that have been printed make it desirable to present the evidence obtained up to date, even though many more years will be necessary for the conclusion of careful systematic investigation under crop and field conditions.

The availability of potash contained in feldspathic rock must depend upon several important considerations, which can best be expressed by a discussion of the following questions:

(1) Is the potash locked up in feldspar and the feldspathic rocks, such as granite, gneiss, rhyolite, syenite, etc., to any extent available as a fertilizer when these rocks are crushed or ground to fine powder?

(2) If the first question can be answered in the affirmative, what influence does fineness of grinding have on the question, and to what degree of fineness is it necessary to grind in order to make a sufficient amount of potash available in the first season after application?

(3) What would be the cost of using ground rock in place of the soluble compounds which up to the present time have been exclusively used, and would there be economy in so doing?

(4) Could any subsequent damage result from the use of ground rock; and if so, how would such damage compare with that which follows the continued use of soluble compounds, such as chlorids, sulphates, and carbonates?

(5) If it should be determined that the potash in ground feldspathic rock is only partially available as a fertilizer, is there any method or process by which the ground rock could be treated so as to increase this availability?

THE AVAILABILITY OF POTASH IN GROUND ROCK.

The attention of the writer was first turned to the availability of potash in ground rock by a study of the decomposition which takes place when various rocks are used to form the surface of macadam roads. The binding power of rock dust depends upon the decomposition of the particles under the action of water and other substances. It has always been believed heretofore that only the potash that could be leached or dissolved out of a finely ground material with water was available for plant growth. As a matter of fact even the most finely ground feldspar which it is possible to obtain yields extremely minute quantities of potash to actual solution in water. Feldspar which contained about 10 per cent of potash and was ground to a very fine powder yielded only 0.025 per cent to solution in water, and only 0.036 per cent to the action of a dilute acid. A large number of similar observations has led to the confident belief, almost universally held for many years, that although rocks which were disintegrated by natural processes served as the original source of potash, the action was so slow that it would be useless to grind rocks and attempt to use them as fertilizers. In the writer's investigations, however, evidence has been obtained which seems to show that decomposition of fine-ground feldspar goes much farther than was indicated by the simple solution tests with water and dilute acids. By the use of laboratory methods it has been shown that almost complete decomposition can be made to take place in comparatively short periods of time under the action of water alone. In order to accomplish this result it has been necessary to use a method by which the potash is continually removed as fast as it is set free from its combinations in the rock. Now, as the roots of plants are continually performing this function, it is possible that in nature the decomposition of the feldspathic particles in the soil must be continually going on as long as the product is being used, and slowing down to the stopping point when no removal is effected by plant growth. For further information on the scientific discussion of the decomposition of the feldspars the original papers should be consulted.[a]

The fact, frequently cited and familiar to almost every person, that rocky hillsides with little or no soil can support growths of timber, would appear to demonstrate that rock potash is available. When it is remembered that wood ashes contain anywhere from 5 to 12 per cent of potash, it will be seen that a large tree represents, as it stands, a considerable quantity of this substance. However, trees

[a] Bul. 92, Bureau of Chemistry, U. S. Dept. of Agriculture; Cir. 38 and Bul. 28, Office of Public Roads.

take a long time to grow, and this present inquiry is mainly confined to availability in a single year from finely ground material.

In order to put the availability of the potash in very finely ground feldspathic rocks to actual test the writer undertook some preliminary experiments in the greenhouse. Tobacco was selected for the experiments because, besides being extremely dependent upon an abundant potash supply, this plant is particularly well adapted to observation and control. Artificial soils were made up of clear, close-grained white sand and finely ground feldspar, running about 8 per cent potash, such as is ordinarily prepared for use in the potteries, and which will pass through a standard sieve of about 200 meshes to the linear inch, having apertures approximately 0.0024 inch square. Tobacco seedlings were set out in this mixture and carefully fed from day to day with dilute solutions of ammonium nitrate and ammonium phosphate in order to supply the necessary amount of nitrogen and phosphoric acid. In addition to this, a small amount of salts, containing lime, magnesia, and iron, was also added to the food solutions. Every care was taken, however, to see that no potash, except that which might be supplied by the feldspar, obtained access to the plants.

For the sake of comparison, plants were also grown at the same time in a rich composted loam soil, which contained an abundance of all plant foods, including potash. Although the artificial sand-feldspar soil was hard and apparently unsuited to the growth of plants, the tobacco nevertheless throve well in it, and showed at no time the slightest indication of potash starvation. When the experiments were finally abandoned, the tobacco plants growing in the sand feldspar had attained a height of about 3 feet, and showed every indication of being as perfectly nourished as those growing in the rich soil.

In addition to the above experiments, seedlings were also set out in a poor, unfertilized soil, with and without the addition and admixture of a certain proportion of the ground feldspar. Here also the availablity of the feldspar potash was clearly indicated.

These experiments, which were made in the summer of 1905, were not considered conclusive, but were sufficiently encouraging to justify further and more systematic investigation. Before proceeding it was of course necessary to look up the literature of the subject, in order to see to what extent ground feldspar had been experimented with by other investigators. A bulletin of the United States Department of Agriculture, which appeared a short time after the conclusion of the preliminary experiments described above, contains a partial reference list of previous publications along this line.[a]

[a] Bul. 30, Bureau of Soils, U. S. Dept. Agriculture, p. 26.

On account of the great interest which has been aroused in this important subject and in order to present all the facts in the most accurate manner, the work of previous experimenters will be given in as much detail as space will permit. It is the intention to bring together all the information and evidence that the literature of the subject affords, whether it appears to be favorable to the use of ground feldspar, or the reverse.

In 1849 Salm-Horstmar[a] published in a German scientific journal a method of preparing an artificial soil which, while being open, porous, and of a soft texture, should be absolutely free from all plant foods except those which were purposely added to it. The purest crystallized sugar was burned to a light form of charcoal and found to be absolutely free from any impurity capable of furnishing nourishment to plants. All sorts of different substances were then added to this material in other pots, and plants grown in them. In this way the experiments were kept under accurate observation and much information was obtained of the actual foods, and their forms, which are necessary to carry on the nourishment of plants. A short time after this investigation, in 1850, a chemist named Magnus[b] repeated these experiments, and also made others. In addition to the pots filled with sugar-charcoal, some of the pots were filled with coarsely pulverized feldspar. It was found that the plants growing in the feldspar made a good growth, even if no other food containing potash was added. The finer the feldspar was ground the better was the development of the plants. Magnus summed up the results of his investigations as follows:

(1) In the absence of all mineral plant foods, barley attained a height of about 5 inches only before dying.

(2) The addition of very small amounts of mineral plant foods enabled the plants to reach complete development.

(3) If too much plant food was present, the plants were stunted or refused to grow at all.

(4) In pure feldspar barley made complete development and matured grain.

(5) The development of growth varied with the coarseness or fineness of the feldspar.

In 1861 Reichardt,[c] a distinguished agricultural chemist, advanced the opinion that granite, porphyry, and other rocks rich in orthoclase feldspar quickly give up their potash to plants when the particles are very fine.

About 1884 Hensel,[d] a German writer and chemist, advocated the use of ground rock or so-called "stone meal," not only in order to supply the requisite potash, but also the phosphates and other mineral

[a] Jour. für Prakt. Chem., 1849, 46, 193.

[b] Ibid., 1850, 50, 65.

[c] Ackerbau Chemie (1861).

[d] A. J. Tafel, Bread from Stones, 1894.

plant foods, such as lime, magnesia, iron, and manganese. This author published a philosophical work entitled "Das Leben," which treated in part of the use of rock fertilizers. Hensel thought that the use of excreta, offal, and other decaying and waste material as manure was harmful, if not to plants, at least to animals and men who subsisted upon them. Like many enthusiasts, Hensel appears to have been completely carried away by his ideas, which were not always justified by known facts. Hensel obtained, nevertheless, a considerable following[a] and factories were established to prepare stone meal. The subject evoked much discussion in Germany for many years. Whether rightly or wrongly, Hensel's ideas provoked the antagonism of nearly all the leading exponents of agricultural science in Germany. A great many experiments were undertaken and in many cases the stone meal as prepared by the factories was shown to be very low in plant foods and nearly worthless as a fertilizer.

Among the prominent agricultural chemists who waged war on Hensel's stone meal were Wagner,[b] Böttcher,[c] Steglich,[d] Hentschel,[e] Pfeiffer and Hansen,[f] and Morgen.[g]

In some respects Hensel's arguments were not without weight, and he was keenly aware of the necessity for very fine grinding before the mineral constituents of rocks could be considered as practically available. The following quotation[h] from a translation of Hensel's work stands for itself:

> The practical point to settle is how far fertilizing with stone meal pays, what yields it will afford; thus, whether it will be profitable for the farmer to use it. * * * It must here be premised that the fineness of the stamping or grinding and the most complete intermixture of the constituent parts are of the greatest importance for securing the greatest benefit of stone-meal fertilizing. A manufactured article of this kind has recently been submitted to me which showed in a sieve of modern fineness three-fourths of the weight in coarse residuum. But as the solubility of the stone meal, and thus its efficiency, increases in proportion to its fineness, the greatest possible circumspection is required in grinding it. The finer the stone dust the more energetically can the dissolving moisture of the soil and the oxygen and nitrogen of the air act upon it. A grain of stone dust of moderate fineness may be reduced in a mortar of agate perhaps into twenty little particles, and then every little particle may be rendered accessible to the water and the air, and can, therefore, be used as plant food. Thence it follows that one single load of the very finest stone meal will do as much as twenty loads of a coarser product, so that by reducing to the finest dust, the

[a] Pomol. Monatshefte, No. 1 (1892); also Wegweiser zur Gesundheit, September 15, 1891.

[b] Zeit. Landw. Vereine Hessen, 1894, 64, 14.

[c] Centbl. Agr. Chem., 1895, 24, 363.

[d] Ibid., 1895, 24, 423.

[e] Ibid., 1896, 25, 136.

[f] Ibid., 1896, 25, 802.

[g] Ibid., 1898, 27, 743.

[h] A. J. Tafel, Bread from Stones, 1894, p. 53.

cost for freight and carriage and the use of horse and cart would amount to only one-twentieth. Therefore we can afford to pay unhesitatingly a higher price for the finest stone meal that has been passed through a sieve than for an article that may be not so much a fine powder but rather a kind of coarse sand.

Inasmuch as this bulletin is interested mainly with the inquiry concerning the use of fine-ground feldspar or feldspathic rocks known to be rich in potash, no greater space need be given the German stone meal discussion.

Some experiments were carried out in 1887 on the use of ground feldspar as a fertilizer by Aitken, a Scotch agriculturist, and chemist to the Highland and Agricultural Society of Scotland. Aitken does not say that he was aware of the work of Magnus or the deductions of Hensel. The record of these experiments is given in the author's own words:[a]

We are familiar with the fact that feldspar, under the slow but constant action of those forces included under the name of weathering, becomes disintegrated and decomposed, and that the potash it contains is dissolved away from it by rain, so that streams emanating from districts where feldspathic rocks abound are found to contain potash salts, and the level straths laid down by the prolonged action of these streams yield fertile soils that are rich in potash. These soils are the product of natural agencies that have been going on for centuries, and the store of soluble potash salts they contain has been increased to an untold extent by the slow solvent action of the roots of plants that have grown on them, so that the conversion of feldspathic rock into soil so rich in potash as to afford an abundant supply of that constituent for the raising of agricultural crops is the product of the work of centuries. At first sight, it might seem a foolish thing to expect that by merely grinding feldspathic rock, and strewing the powder upon soils deficient in potash, the long natural process referred to should be so accelerated as to cause the feldspar to act as a source of potash for the immediate use of the growing of crops whose vigorous growth demands a relatively large amount of that substance. Nevertheless, the striking results of an experiment made at the society's experiment station at Pumpherston showed that such an expectation was not altogether unreasonable. Ground phosphates had been used as a phosphatic manure with varying success for some years, and as it seemed that the varying nature of the results obtained might be due to the varying degrees of fineness to which phosphates were ground. I made a small preliminary experiment, in which the same phosphate was applied in different degrees of fineness, and I found that the more finely ground the phosphate the more effective was it as a manure. A similar experiment on a larger scale is described in the present volume of the Transactions, page 245, where it is seen that the efficiency of ground phosphates is in direct proportion to their fineness. It therefore seemed reasonable to suppose that feldspar, although it is a very insoluble substance, might, if it were ground to an exceedingly fine powder in certain circumstances, be found to yield to the action of the solvents in the soil and in the roots of plants so rapidly as to be available as a source of potash to some crops, even during the short period of a single season.

Accordingly I obtained, through Mr. Bödker, the Swedish and Norwegian consul here, at whose instigation the experiment was undertaken, a supply of very

[a] Trans. Highland and Agr. Soc. Scotland, 1887, ser. 4, 19, 253.

pure feldspathic rock, rich in potash, of which enormous quantities are to be had in Norway. It was ground as finely as possible by Messrs. J. & J. Cunningham, of Leith, and thereafter sifted through a sieve of 120 wires to the linear inch, and was found to contain about 12 per cent of potash. The whole quantity of sifted feldspar was very small, less than a half hundredweight, and as it was received late in the season, the experiment was made simply to afford information which might indicate whether it was desirable to try the experiment on a larger scale the following season. There were two small experiments made—one by Mr. R. Shirra Gibb, at Boon, on a crop of peas, and one at Pumpherston on turnips. The experiments were on plots of one-fortieth acre, and the following were the manures employed and the results obtained:

	Kind and quantity of fertilizers.	Peas.		Turnips.
		Dried in bulk.	Grain.	Bulbs.
		Pounds.	*Pounds.*	*Pounds.*
1.	Sulphate of potash, 3 pounds Sulphate of lime, 3 pounds Superphosphate, 6 pounds	114	3.8	482
2.	Ground feldspar, 12 pounds Sulphate of lime, 3 pounds Superphosphate, 6 pounds	102	3.5	496
3.	Sulphate of lime, 3 pounds Superphosphate, 6 pounds	96	.....	476

Although the whole experiment is on a small scale, and the crops are below the average, there is nevertheless a clear indication that the feldspar has acted as a potash manure. In both cases where no potash was applied the crop is the smallest. At Boon the plot with no potash was unable to mature its seed, so that it could not be thrashed, while on the other two plots the amount of seed was not very different, and quite in proportion to the total crop, viz, about one-fortieth. The smallness of the crop does not detract from the value of the experiment as a means of indicating whether or not feldspar acts as a potash manure. Had the crop been sown at the proper time it would have been much larger. In the case of the turnip crop the ground feldspar has done better than the sulphate of potash. That may be accidental, but it may be that the insoluble form in which potash is contained in feldspar is more favorable for turnip growing than the soluble sulphate. Soluble potash manures, when applied to the turnip crop, sometimes diminish rather than increase the crop, and this is especially the case where the crop is dunged in the drills; but no dung has been put on the Pumpherston station these twelve years, and the results obtained all over the field show that potash is now required for turnip growing on that land.

Upon the whole, the result of this experiment may be taken as showing that potash feldspar when ground to an exceedingly fine powder is capable of acting as a potash manure even in a single season.

In 1889 the Maine State experiment station,[a] under Balentine, independently of any previous experimenters, investigated the use of ground feldspar as a source of potash on oats. The results are given verbatim from the records of the station:

In connection with the experiments with finely ground phosphatic rock as a source of phosphoric acid for plants, pot experiments have been undertaken to determine to what extent plants can avail themselves of the potash of potash

[a] Ann. Rept. Maine State Col. Exp. Sta., 1889, p. 143.

feldspars. The pots used for the experiments were like those used in the phosphate experiments. They were also filled in the same manner, having first a layer of gravel at the bottom and above this 65 pounds of quartz sand, with the last 35 pounds of which were mixed the experimental fertilizers.

Three pots, 1, 5, and 9, were supplied each with 10 grams of feldspar carrying 11.61 per cent of potash, 10 grams of nitrate of soda, and 10 grams of acid South Carolina rock. Three other pots, 13, 17, and 20, were fertilized with 20 grams of feldspar and the same amount of nitrate of soda and acid phosphate as was supplied to 1, 5, and 9. In these pots were planted oats. When the oats were 2 or 3 inches high they were thinned out to 18 plants per pot. The pots were watered in the same manner as were those in which the experiment with phosphates was conducted.

In the table below are shown the results of substituting muriate of potash for feldspar as a source of potash:

Kind and quantity of fertilizers.	Number of pot.	Yield of grain, in grams.	Yield of straw, in grams.
10 grams feldspar	1	18.37	47
10 grams nitrate of soda	5	14.37	43
10 grams acid South Carolina rock	9	19.43	47
20 grams feldspar	13	17.28	47
10 grams nitrate of soda	17	16.78	47
10 grams acid South Carolina rock	21	16.83	52
3 grams muriate of potash	16	22.88	67
10 grams nitrate of soda	20	18.85	72
10 grams acid South Carolina rock	24	24.37	65

The pots receiving 10 grams of feldspar produced, on the average, about 79 per cent of the average of the grain produced by those pots receiving 3 grams of muriate of potash having 50 per cent of actual potash. The amount of grain was not increased by increasing the feldspar to 20 grams, though there was a slight gain in straw.

The conclusion to be drawn from the experiment is that the oats were able to draw from the feldspar potash enough for a large crop of grain. If this conclusion is verified by future work, some of our feldspars may prove a cheap source of potash to the farmers of the State.

Examination of the figures given in the above table shows that the potash from the feldspar undoubtedly became available, but was not as efficient as that from the more soluble muriate.

In 1889, the same year that the results of these experiments were made public, Nilson [a] in Sweden published an investigation in which fine-ground feldspar prepared for the potteries was tested in comparison with potassium sulphate. Oats were used, and the experiments were carried out on the Swedish moor soils, which, in a dry condition, already contained 0.5 per cent of potash, although only 0.03 per cent of this was soluble in dilute acid. There were 300 kilograms (660 pounds) of slag phosphate, 50 kilograms (110 pounds) of nitrogen in the form of Chile saltpeter, and 80 kilograms (176 pounds) of potash as sulphate or 200 to 300 kilograms

[a] Landtbr. Akad. Handlingar och Tidskr., 1889. See also Centbl. Agr. Chem., 1889, 18, 608.

(440 to 660 pounds) as ground feldspar added to the hectare (2.47 acres). The results of weighings of crop yield, made on the basis of 100 plants from each trial, are given in the following table:

Weight of crop of oats from seven plats of 100 plants each, grown with various fertilizers.

Kind of fertilizer.	No.	Grain.	Straw.	Chaff.	Total.	Equivalent yield of grain per hectare.
		Grams.	*Grams.*	*Grams.*	*Grams.*	*Kilograms.*
Unfertilized	1	5.3	11.0	1.0	17.3	21[illegible]
Phosphate and potassium sulphate	2	157.3	220.5	16.3	394.1	6,400
Phosphate and 300 feldspar potash	3	133.8	178.7	15.5	328.0	5,450
Phosphate and Chile saltpeter	4	175.5	242.8	21.2	439.5	7,150
Phosphate, Chile saltpeter, and potassium sulphate	5	232.5	346.2	24.8	603.5	9,470
Phosphate, Chile saltpeter, and 200 feldspar potash	6	171.5	245.2	21.3	438.0	7,000
Phosphate, Chile saltpeter, and 300 feldspar potash	7	177.7	262.5	23.5	463.7	7,240

Nilson's results are most unfavorable to ground feldspar, as an inspection of the figures shows, but as a very good yield was obtained by the use of Chile saltpeter and phosphate without any additional potash, the experiments are not very conclusive. Chile saltpeter is a crude nitrate of soda which sometimes contains potash salts. It is possible that in all these experiments there was a tendency to overfeeding rather than to underfeeding.

In 1890 Sestini[a] published the results of a very interesting investigation of the decomposing action of plant roots on feldspar. A coarse feldspathic granite sand from the island of Elba was first carefully washed to remove all adherent earth or plant food, and then mixed with certain amounts of carbonate, phosphate, and sulphate of lime. The nitrogen was supplied in the form of ammonium nitrate. Various plants and grasses were grown in this mixture under very careful test conditions. The crops matured well, and at the end of about a year it was shown that a very considerable decomposition of the feldspar had taken place. Sestini concluded that the decomposition of the feldspar went on much more rapidly under the influence of plant growth than had previously been supposed.

In 1901 Headden,[b] working at the Colorado experiment station, also independently, carried on some interesting experiments on the availability of potash contained in ground feldspar. To quote this author's own words:

> We endeavored to determine whether the feldspar could furnish potash to plants. For this purpose the perfectly fresh mineral was used, pulverized as already described in imitation of the soil, i. e., the particles varied from

[a] Landw. Vers. Stat., 1900, 54, 147.

[b] Bul. 65, Colorado Exp. Sta., p. 30.

1 millimeter in diameter to an impalpable powder. This was mixed with pure quartz sand. Bone ash was used to supply lime and phosphoric acid. The sample used contained no potash. Nitrate of lime furnished the nitrogen. Chlorine was furnished by a minute quantity of calcic chloride. Distilled water was used throughout the experiment.

The plants grew healthily in this mixture until the floors of the building were oiled and the room in which the plants were growing was shut up and became too warm; these two things together gave them a decided setback, and later a thrips, *Thrips striata* according to Professor Gillette, attacked the plants and did them much damage. Some of the plants, however, seeded. They were harvested, though in bad condition and very uneven in the degree of their development. The root system was well developed, the sand being filled with the roots. The weight of the tops as harvested was 198.5 grams; that of the roots as washed out was 40 grams. The tops and roots were incinerated together and yielded 5.795 per cent of soluble and 9.803 per cent of insoluble ash, a total of 15.598 per cent.

Examination of the feldspars used showed the presence of 11.993 per cent of potash and 2.988 per cent of soda. Phosphoric and sulphuric acids were present in very small quantities; the former equaled 0.041 per cent and the latter 0.003 per cent of the feldspar.

The nitrogen in the oat hay, roots included, was 3.2543 per cent.

The ash gave the following analysis:

	Per cent.		Per cent.
Carbon	0.17	Calcic oxide	21.70
Sand	8.13	Magnesic oxide	3.90
Silicic acid	15.73	Ferric oxide	.96
Sulphuric acid	4.41	Aluminic oxide	.31
Phosphoric acid	3.98	Manganic oxide	.16
Carbonic acid	15.35	Ignition	2.61
Chlorine	2.73		
Potassic oxide	15.95		100.71
Sodic oxide	4.62		

This ash is very anomalous in its composition as well as in the quantity present in the plants. The plants were not evenly matured at the time of gathering and were in bad condition. The question we endeavored to investigate, however, is perfectly answered by the results, i. e., the oat plant can use the finely divided feldspar as a source from which to obtain potash, for in this experiment, made under very adverse conditions, we found that the oat plants took from the feldspar 1.4417 grams of potash. The potash added in the seed has been deducted. The silicic acid appropriated by the plant indicates the decomposition of the silicate.

In 1905 Prianischnikow,[a] a Russian investigator, published the results of a series of pot tests using feldspar and mica as sources of potash. The feldspar used was ground so that it was less than 0.25 mm. in diameter, corresponding to an 80-mesh sieve. The material was mixed with sand and the other foods added in the form of phosphates and nitrates of lime and soda. The cultures used were tobacco, buckwheat, flax, peas, sunflowers, and barley. The tabulated results are too voluminous for insertion here, but they appear to show that

[a] Landw. Vers. Stat., 1905, 63, 151.

the feldspar, even in large amounts, had little or no effect on the growth of the plants. The investigator concluded that mica is, if anything, a better source of potash than feldspar, but that neither of these minerals supplies a sufficient quantity to make them worth the slightest consideration so far as plant growth is concerned. The only criticism of these experiments that might be offered is that 80-mesh feldspar powder is far too coarse to be used in pot experiments. This point will be taken up more fully later on.

The most important researches which have ever been published tending to show that under certain conditions finely ground feldspar is worthless as a fertilizer are those of von Feilitzen.[a] This experimenter, like Nilson, worked on Swedish moor soils. He concluded that ground feldspar is almost worthless as a fertilizer. The results and conclusions are best shown by abstracting from a translation from von Feilitzen's publications:[b]

Potash, as is well known, is one of the necessary constituents of plant food; consequently, if it is absent in the soil or only there in insufficient quantities, a normal development of the higher orders of plants is not possible. According to the researches of plant physiologists, it is particularly instrumental in the formation and transport of the carbohydrates (sugar, starch, etc.), for which reason potash plays such a prominent part in the manuring of potatoes, turnips, and other root crops, but it is also required for cereals and all the other cultivated plants. Of late, comprehensive experiments have been carried out by Prof. Dr. H. Wilfarth at the experimental station at Bernburg, with the view to ascertain in what way the want of one or several of the necessary constituents of plant food influenced the development and appearance of plants. On this occasion he found that the want of potash caused a defective growth of some of the vegetative parts, the leaves of potatoes, tobacco, buckwheat, and beetroots assuming a speckled appearance.[c] Certain clearly defined portions, especially at the borders of the leaves, grew yellowish-white and decayed, while the other parts retained their original appearance. These marks are often very much like those caused by fungi and insects, but if examined more closely it becomes evident that they can not be due to such causes.

In 1903 we made quite similar observations, when experimenting with clover and timothy grass, and, as it should be of interest, I shall describe in short the observations made by us. In 1902 a series of experiments were prepared in plots of soil of 1 square meter each (about 1 yard square), charged with rather well-decayed reed grass turf, poor in potash, in order to investigate whether the potash in a mineral fertilizer, prepared in Sweden, was of any manurial value. As, by analysis, this fertilizer turned out to be finely ground feldspar, we were prepared for an unfavorable result at the very outset.

The fineness of the ground feldspar is not given, but an analysis showed that it contained 8.15 per cent of potash. The experimental series was made up of two plats, each fertilized as shown in the following table, and in May, 1902, they were sown with a clover-grass

[a] Exp. Sta. Record, U. S. Dept. Agriculture, 1904, 16, 30.

[b] How Deficiency in Potash Affects Clover and Timothy.

[c] Jour. für Landw., 1903, No. 11.

mixture containing red clover, bastard clover (alsike), white clover, and timothy grass. Even in the first year the grass developed vigorously and produced vegetable matter, as shown in the table. An average of 1 square meter of each of the two parallel plats was taken. Fifty-four pounds of phosphoric acid were used on each plat.

Plat number.	Kind and quantity of fertilizer per acre.	Green vegetable matter produced—average of 2 plats.	Increase due to potash—average of 2 plats.
		Pounds.	*Pounds.*
1	Without potash and with 357 pounds of basic slag	1.20	.....
2	With 89 pounds of potash as potash manure salt	4.53	3.33
3	With 89 pounds of potash as ground feldspar	1.69	.49
4	With 178 pounds of potash as ground feldspar	1.96	.76

These figures show that this soil responded very well to the application of the soluble potash salts. While it must be admitted that the ground feldspar was somewhat available, the effect appears to have been inconsiderable.

It is hard to reconcile such contradictory results as these which are given at length in the preceding pages. The only thing that can be said at the present time is that careful and systematic tests are required in order to determine finally to what extent and under what conditions ground feldspar can be economically used in agriculture. The inference to be drawn would seem to be that under certain conditions finely ground feldspar is at least partially decomposed, so that its potash becomes sufficiently available to be made use of by certain crops. Under other conditions we are forced to the conclusion that ground feldspar is of little value as a potash fertilizer.

Before proceeding with the description of experiments carried on by the Department of Agriculture it will be necessary to define, as briefly as possible, total and available potash, as the terms are commonly used. Potash is the name given to the oxid of the metallic element potassium. The name is derived from the fact that potash at one time was principally obtained by leaching wood ashes in large iron pots. The letter K is used by chemists as the symbol for potassium, the German name for which is Kalium. The oxid is written K_2O, which signifies that two atomic weights of potassium unite with one atomic weight of oxygen to form potash. Potash as such is a strongly caustic substance which unites with water to form a compound technically known as lye. Fertilizers, both natural and artificial, contain potash, invariably combined with some acid to form a compound or salt, such as sulphate, chlorid, carbonate, nitrate, phosphate, or silicate. Although potash (K_2O) does not exist free in a fertilizer, the potassium present in whatever form is figured and reported as total potash (K_2O). Owing to the belief that has

always been held by the majority of chemists and agriculturists that the potash combined as it is in the mineral silicates becomes soluble with extreme slowness, if at all, it is customary to distinguish between available and total potash. According to the official methods in vogue in this country the available potash is determined by boiling 10 grams of the sample with 300 grams of water thirty minutes and analyzing the water extract. In different places different methods are used; in some cases acid solutions are used to extract with, so that it is difficult to give an exact definition of available potash. However, it may be defined as all the potash that is present, in whatsoever form, which the crop can make use of in one crop season. The textbook definitions, as well as the State fertilizer laws, are in need of revision in this particular respect. This is especially true in view of the fact that the value of a mixed fertilizer is figured, as far as potash is concerned, on the available or water-soluble potash alone. Even the potash contained in such organic fertilizers as cotton-seed meal and tobacco stems, which undoubtedly becomes available in one season, is not estimated as being available by the present methods of analysis, and therefore in many cases great injustice is done to manufacturers of mixed fertilizers, who should certainly be entitled to all the plant food contained in their mixtures which can be made use of by a crop in a single growing season.

Tobacco is particularly dependent upon abundant supplies of potash. In some of the tobacco-growing districts barnyard and stable manures are used, often enriched with an addition of commercial fertilizers. Since sulphates and muriates of potash are found to be harmful in certain ways to high grades of tobacco, the use of the strongly alkaline potassium carbonate has been largely resorted to on the tobacco crop. Potassium carbonate, which contains about 66 per cent of potash (K_2O), is an expensive compound, costing $90 to $95 per ton, f. o. b. port of entry, or 6 to 7 cents per pound of unit potash. In addition to the cost of this salt, its strong alkalinity is an objectionable feature, and it is a grave question whether the annual addition to the land of a superabundance of such an alkaline salt will not be followed by an actually harmful effect. In view of the successful results which have attended the efforts of the Bureau of Plant Industry[a] to improve the quality and yield of native tobacco by proper selection and breeding, it was decided to make a systematic investigation of the possible use of ground feldspar as a potash fertilizer.

Preliminary to the field and crop experiments which were to follow later, greenhouse experiments were begun early in the winter of

[a] Bul. 96, Bureau of Plant Industry, U. S. Dept. of Agriculture; Yearbook Dept. Agr., 1905, p. 219.

1905-6. Three large beds in the greenhouse, all having the same dimensions ($21\frac{3}{10}$ feet by $6\frac{2}{5}$ feet by 5 inches), were filled with a common unfertilized meadow soil taken from the surface after the removal of sod and grass roots. Four pounds of ground bone phosphate were broadcasted and well worked in.

Bed No. 1 now received 2 pounds of potassium carbonate containing about 67 per cent of potash (K_2O). In order that the potassium carbonate might be evenly distributed, it was dissolved in 2 gallons of water and sprinkled evenly over the bed. After drying out, the earth was again well worked.

Bed No. 2 received 17.4 pounds of finely ground potter's feldspar containing 8.3 per cent of potash (K_2O). This was also broadcasted and well worked in. It will be seen that beds 1 and 2 contained nearly equivalent amounts of potash, the only difference being that in one case the soluble carbonate was used and in the other ground rock.

No potash in any form was added to bed No. 3, which was used for comparison. The soil itself, however, contained about 0.5 per cent of total potash, and as the filtered Potomac River water which it was necessary to use for watering throughout the entire experiment contains an amount of potash equal to about 2 parts per million, the tobacco on bed No. 3 did not at any time show the effect of potash starvation.

All three beds were supplied with a sufficient quantity of nitrogen in the form of pure ammonium nitrate. The seed chosen for the experiments was carefully selected Cuban wrapper tobacco. In making experiments of this kind it is necessary to select seedlings as nearly as possible of equal vigor. It is not improbable that many wrong deductions have been drawn from pot or plat experiments in which the need for careful selection of seed has been overlooked.

Tobacco seedlings were set out in four rows of ten plants each in the three beds. The tobacco crop is usually planted with about 8,000 plants to the acre, so that the experimental plats represented, as far as plant growth was concerned, one two-hundredth of an acre. The actual amount of potash added to plats Nos. 1 and 2 was equivalent to 280 pounds to the acre. As the original soil contained a sufficient amount of potash to mature some sort of a crop on plat No. 3, it is not possible to state the actual amount of potash present in the three plats. The potash in the soil was not water soluble and would not have been termed available in the present sense of the word.

The tobacco grew well throughout the experiment, and for the first six weeks very little difference was noted. After this time, however, it became evident that the plants in plat No. 3 were falling behind. At the end of twelve weeks the plants in plat No. 3 were plainly

stunted and much less developed than those in the other two plats. The tobacco grown in plats Nos. 1 and 2 was evenly developed, fully matured, and of a good quality. It was carefully harvested in the usual way and the yield of green tobacco weighed. After curing, the actual yield of leaf was also recorded. The results, which are shown in the following table, appear to indicate that the feldspar potash was available to quite the same extent as that which was added as potassium carbonate:

TABLE III.—*Results of greenhouse experiments with tobacco plants.*

No. of plat.	Source of potash.	Actual weight of green crop.	Estimated weight of green crop per acre.	Actual weight of cured leaf.	Estimated weight of cured leaf per acre.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
1	Potassium carbonate	154.0	30,800	5.70	1,140
2	Ground feldspar	155.0	31,000	6.30	1,260
3		128.5	25,700	5.30	1,060

These yields do not in any case equal those obtained in the field under the best crop conditions, but for a winter greenhouse crop raised in shallow beds they are satisfactory.

On the completion of the greenhouse experiments arrangements were made to carry on field trials in Connecticut and Florida under standard crop conditions. In the tobacco-growing district of Connecticut it is customary to use from 150 to 250 pounds of carbonate of potash to the acre of tobacco. The cooperation of several prominent tobacco growers was obtained, who each agreed to try an acre, substituting for the usual carbonate 1 ton of potter's spar, running 8.3 per cent of potash, or 186 pounds to the ton. The broadcasting and working in of the feldspar was done under the personal supervision of representatives of the Department of Agriculture, and none of the experimental acres received any potash except that contained in the ground spar. All the experimental fields did as well as any in their neighborhood and matured excellent crops. The following letters were received from the growers themselves in regard to the use of feldspar:

TARIFFVILLE, CONN., *February 11, 1907.*

DEAR SIR: In reply to your letter of February 5, I would say that I used the ton of finely ground feldspar as a potash fertilizer for tobacco, and used no other form of potash on the plat in connection with the feldspar. This plat (one-half acre) was treated exactly like the rest of our tobacco lands as regards nitrogen, phosphoric acid, lime, etc.

We had a fine large growth of tobacco where the feldspar was used; fully as large as any in our fields, and much larger than in some sections of our fields.

I do not consider this an absolute or hardly a fair test of the feldspar, as it was used on land that had previously grown tobacco for several years, and each

year we had fertilized heavily with carbonate of potash. I will be pleased to give you more detail if you wish.

Yours respectfully, J. S. Dewey.

Hartford, Conn., *February 7, 1907.*

Dear Sir: In reply to your letter of February 5 regarding the finely ground spar, would say that we used this material as a potash fertilizer as directed by you last spring. This was used on comparatively new land, tobacco having been grown only one season previous to this past season. During the growing season we could not see any perceptible difference on the same land between this tobacco and that treated with carbonate of potash, planted side by side. We hung this tobacco in the same shed, it being cut at the same time, where we were able to identify it after it was cured. We are glad to report that the tobacco grown where the ground feldspar was used was exceptionally nice tobacco. It was so pronounced by tobacco experts who have examined it.

The tobacco grown on the same character of land beside where this was grown was exceptionally nice tobacco, but we think if there was any preference it would be for that grown on the feldspar. It certainly was beautiful in every respect. We should be very glad to conduct an experiment on 1 acre or less on new land that has never grown crops of any kind or been fertilized in any way by stable manure or other fertilizer, and follow this up for, say, three years. We have a piece of land we think well adapted to make the experiment. The result this past year has been so gratifying that we would be very glad to carry it a little further, if possible.

Any further information we can give you we will be glad to furnish.

Yours truly, Olds & Whipple.

Suffield, Conn., *February 16, 1907.*

Dear Sir: Yours received inquiring about the finely ground feldspar sent me. Would say that I used it on 1 acre of tobacco and got very satisfactory growth. The only difference I could detect in tobacco grown on this acre and the adjoining land, where I used cotton-hull ashes for potash, was that the burn of the tobacco grown on the latter was not quite as clear as that of the tobacco grown on the feldspar.

Yours respectfully, Edmund Halladay.

Quincy, Fla., *March 7, 1907.*

Dear Sir: In reply to your favor, I beg to state that 1 acre of tobacco was grown here last year on ground feldspar, and as far as we were able to tell from the appearance of the tobacco in the field the growth was equally as good as where other forms of potash were used. Mr. Underhill, who used this feldspar, was not able to harvest the tobacco separately on account of scarcity of labor in harvest season.

I am planting some plat experiments this year in which I have included the ground feldspar, to be compared with other forms of potash, and hope to get some information in this way. In addition to this I shall put out at least 2 acres of feldspar as a substitute for carbonate of potash, and will report results at the end of the season.

Yours very truly, W. W. Cobey.

Although it is admitted that these experiments have not as yet proved the value of ground feldspar for tobacco, it is quite certain that the experimental crops found all the potash they required. If

we assume that von Feilitzen and others are right and that the feldspar is of little or no value, we must conclude that the practice of adding potassium carbonate each year to the tobacco fields is unnecessary.

Many attempts have been made by the writer to devise crucial tests which would show decisively whether or not the ground feldspar is actually capable of giving up potash to growing plants. One of these experiments, which was undertaken in cooperation with Dr. L. J. Briggs, of the Bureau of Plant Industry, is interesting on account of its direct bearing on this point. A wooden trough of 1 square foot cross-sectional area and 30 feet in length was filled with a poor meadow soil, containing no appreciable quantity of water-soluble potash. About 5 pounds of fine-ground feldspar, containing 9.3 per cent of total potash, was then evenly distributed over the surface of the trough and well worked into the soil. Carbon electrodes of about 1 square foot area were inserted at the extreme ends and tobacco seedlings set out at 1-foot intervals along the trough. The carbon electrodes were connected to a 110-volt direct-current lighting circuit and a current of electricity was passed continuously in the same direction through the soil while the growth of the plants was in progress. The amount of current varied with the moisture content of the soil—between the limits of 5 and 15 milli-amperes. The plants made a flourishing growth, and at the end of several weeks it was apparent that the best growth was being made in the neighborhood of the center of the trough, the plants at the extreme positive and negative ends being more or less stunted. The soil at the beginning of the experiment was neutral to litmus paper. At the end of the experiment, when the plants had attained a maximum height of 2 feet, a sample taken from the positive end of the trough reddened litmus paper, showing it to be decidedly acid. The middle section by the same test was shown to be faintly and the negative end strongly alkaline. While no sweeping deductions can be drawn from the single experiment, it is quite certain that a partial transference of the alkaline bases from the positive to the negative end of the trough had occurred. This effect could only take place with that portion of the bases which had actually passed into solution. The results of this experiment appear sufficiently interesting to warrant repetition under still more careful conditions.

THE EFFECT OF FINENESS OF GRINDING.

From the evidence which has been submitted in the preceding pages it may be safely concluded that the potash contained in ground feldspar is at least in some part available as plant food. The question whether it can be made sufficiently available under certain conditions

to be an economical substitute for concentrated and soluble potash salts remains to be determined by systematic investigation. It may have been noticed in reading the account of the foregoing experiments that in only a few cases was the fineness of the feldspar material described. Each investigator considered ground feldspar fine material, whether it passed an 80-mesh or a 200-mesh sieve. A standard sieve containing 200 meshes to the linear inch has openings 0.0026 inch square. A sieve of 80 meshes to the linear inch has openings about 0.007 inch square. It is never the case, however, that a material which has been ground so that it will just pass a certain sieve will consist of particles of uniform size corresponding to the size of mesh. All ground material contains a certain proportion of very fine particles, down to those which might be characterized as submicroscopic in size. The smaller the coarser particles of a given powder which has been ground in bulk the higher will be the proportion of very fine material. This is a very important point, because it is doubtless true that the amount of decomposition caused by the action of water on ground feldspar is directly proportional to the active surface area presented by unit weights of the powder. To one who has not studied the matter, the rapidity with which surface area rises with fine grinding is very surprising. In a 200-mesh feldspar powder, such as is supplied by the grinder for the pottery trade, the finest particles bear the same relation to the coarsest present as these latter would to fragments about 2 inches in diameter. As the surface area of a powder increases in inverse ratio to the diameter of the particles, it can be seen how quickly the availability due to active surface must increase with fineness in grain. No one would for an instant consider the possibility of fertilizing land by scattering on it feldspar fragments of an average diameter of 2 inches. Yet in grinding these fragments to an 80-mesh powder, we have not increased the active surface area as much as we should do by pushing on the grinding of an 80-mesh powder to the ultimate fineness attainable in mechanical processes. Grinding is making surface, and it can be shown that the availability of potash in ground feldspar increases with the surface area. If feldspar is ground so that it will pass an 80-mesh sieve, it will of course contain a certain proportion of very fine particles, some of which approach the limits of visibility under a powerful microscope. If we carry on the grinding of the material from 80-mesh to 200-mesh, the proportion of the very small particles is enormously increased. The smallest particles which we need to consider here are those which can be measured by a micrometer device connected with the microscope. These smallest particles have a diameter of about 0.0001 millimeter. Now, in order to make a specific example, we will consider the surface areas presented by 1

pound of feldspar in different degrees of subdivision. First, in the form of a solid cube, then broken down to particles that could just pass an 80 and a 200 mesh sieve, respectively, and, finally, in the condition it would be if it were possible to grind all the material as fine as the finest particles which occur in an ordinary 200-mesh powder. The 1 pound of feldspar in a solid cube would have a surface area of 29.3 square inches; particles capable of passing an 80-mesh sieve would give 8.870 square inches; particles able to pass a 200-mesh sieve would give 24.905 square inches; and if it were possible to reduce the powder to particles 0.0001 millimeter in diameter, there would result a surface area of 16,460,000 square inches.

If it were practically possible to collect 1 ton of feldspar all in the state of the finest particles, as shown above, the surface area presented by the ton would be enormous—in fact, it would be equal to 256,000,000 square feet, 5,877 acres, or more than 9 square miles. Now, although such grinding is out of the question at the present time, an ordinary 200-mesh feldspar prepared for the pottery trade, which is valued at about $8 per ton, contains a large proportion of very fine particles. The marvelous rise in the surface area attained by fine grinding is very well exhibited in the figures given, and it is undoubtedly true that previous experimenters have not paid sufficient attention to the percentage of very fine material in the ground feldspar.

One opponent of the use of feldspar has written:[a]

> What we call soil is rock of various sorts crushed or broken up by weather and other agencies. The crushed granite could hardly be more fertile than a good soil. When we think that an acre of soil 1 foot deep weighs over 3,500,000 pounds, we see what a drop in the bucket a few tons of ground rock really amounts to.

As a matter of fact, discussion of the value of a few tons of fine-ground potash-bearing rock, with its millions of square feet of surface area, can not be so easily brushed aside. It is true that the soil contains many fine particles; but those which, like feldspar, suffer decomposition under the action of water have presumably been already decomposed, and this new material is to replace that which has been used up or removed. Each tiny particle of feldspar provides only a small increment of potash, but in a ton of fine-ground material there are many billions of particles.

COST OF GROUND FELDSPAR.

Nearly all of the feldspar which is at present ground to fine powders is prepared, as has been stated, for the pottery trade. For this purpose it is necessary to use mills with specially adapted linings so

[a] The Potash in Crushed Rock, German Kali Works, New York.

that the finished product shall not become contaminated from the contact with iron or steel. The production and cost of feldspar, mainly for the use of the potteries, during five consecutive years, is shown in the following table:

TABLE IV.—*Production and value of feldspar, 1901–1905.*[a]

[Short tons.]

Year.	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1901	9,960	$21,669	24,781	$198,753	34,741	$220,422
1902	21,870	55,501	23,417	194,923	45,287	250,424
1903	13,432	51,036	28,459	205,697	41,891	256,733
1904	19,413	66,714	25,775	199,612	45,188	266,326
1905	14,517	57,976	20,902	168,181	35,419	226,157

[a] Mineral Resources of the United States, U. S. Geol. Survey, 1905.

For fertilizer purposes the fine grinding of feldspar could be done in iron mills similar to those which are used for grinding limestone in the cement industry. The only important points to consider would be the percentage of total potash present and the fineness of grinding. At the present time there are few data available on the cost of grinding feldspar to a 200-mesh powder, but with modern machinery there is little doubt that it can be done much more economically than would have been considered possible only a few years ago. Under the stimulus of the cement industry a great development has been made in recent years in the methods and art of fine grinding. The following table is of interest, as it shows at a glance what the potash in ground feldspar would cost if the percentage is compared with a cost of grinding varying from $1 to $10 per long ton.

TABLE V.—*Price per pound of potash unit in feldspar.*

Potash contained in the feldspar.	Cost of ground feldspar per ton (2,240 pounds).									
	$1.	$2.	$3.	$4.	$5.	$6.	$7.	$8.	$9.	$10.
3 per cent	$0.015	$0.030	$0.044	$0.059	$0.074	$0.089	$0.104	$0.119	$0.134	$0.149
4 per cent	.011	.022	.033	.044	.055	.067	.078	.089	.100	.111
5 per cent	.009	.018	.027	.035	.044	.053	.062	.071	.080	.090
6 per cent	.007	.015	.022	.030	.037	.045	.052	.059	.067	.074
7 per cent	.006	.012	.019	.025	.032	.038	.045	.051	.057	.063
8 per cent	.005	.011	.017	.022	.028	.032	.039	.045	.050	.056
9 per cent	.005	.009	.014	.019	.024	.029	.035	.039	.044	.049
10 per cent	.004	.009	.013	.018	.022	.027	.031	.035	.040	.045
11 per cent	.004	.008	.011	.015	.020	.023	.028	.030	.034	.040
12 per cent	.004	.007	.011	.015	.018	.022	.026	.029	.033	.037
13 per cent	.003	.007	.010	.014	.017	.021	.024	.027	.031	.034
14 per cent	.003	.006	.010	.013	.016	.019	.022	.026	.029	.032
15 per cent	.003	.006	.009	.012	.015	.018	.021	.024	.027	.030

The prices are given in cents per pound, so that if, for instance, rock carrying 8 per cent of potash could be delivered for $9 per ton, the potash contained in it would be added to the land at a cost of 5

cents per pound. At $5 per ton the cost per pound would fall to 28 mills. The figures are of course only applicable provided the potash in the ground material can be proved available as a plant food.

It must be remembered that the only real measure of available potash is that which is made use of by the crop. It is not likely that all the potash added, even in the form of soluble potash salts, is actually used, and the amount that can be supplied by ground rock is still an unknown quantity.

POSSIBLE HARMFUL EFFECTS OF GROUND FELDSPAR.

The question is frequently asked whether there is possible danger to the land in experimenting with the use of ground feldspathic rock. It is well known that in some cases, notably with tobacco, injurious effects are produced by the continued use of the soluble potash salts, particularly the sulphate and muriate. Feldspar grains of various sizes are normally present in many soils; it does not, therefore, seem possible that any harmful effect could follow the application of ground rock. As has been pointed out in an earlier portion of this paper, feldspar consists of the alkaline elements, soda, potash, and lime, combined with alumina and silica. After decomposition, hydrated aluminum silicate, the essential base of all clays, is left behind, the alkalis and the silica being set free in a condition in which they can be absorbed by the root action of plants. It would seem, therefore, that whatever the value of the results obtained no possible harm can follow the experimental use of ground feldspar in reasonable quantities.

EXTRACTION OF POTASH FROM GROUND ROCK.

The discussion of the use of ground rock as a source of potash is not complete unless it includes the extraction of potash by chemical and electrical processes. If future experiments should demonstrate that fast-growing crops are dependent on very soluble forms of potash the question of the extraction of this element from ground feldspar becomes a matter of importance.

The extraction of potash from rock has not as yet been accomplished on a commercial basis, but it has been done in the laboratory, and the method has been published in a recent bulletin.[a] The full details of the investigation are too technical for insertion here, but if the processes described could be carried on at a cost low enough, the potash in ground rock could be rendered sufficiently soluble for all practical purposes. Briefly, the method consists in sliming the ground feldspar with water to which a small quantity of hydrofluoric

[a] Bul. 28, U. S. Dept. of Agriculture, Office of Public Roads.

acid has been added. This slime is placed inside a suitable wooden vessel and a current of electricity is passed through it. The alkali set free by the action of the acid is carried away by the electric current, while the acid appears to be used over and over again. Finally, by combining the acid and alkaline products, a material is obtained in which the potash which has been set free is soluble and available. It is hoped that further investigation will result in some method based on these principles for making the vast quantities of potash contained in feldspathic rocks completely available.

CONCLUSION.

A careful reading of the foregoing pages will show that no claim has been made that ground feldspar is an efficient substitute, under all circumstances, for potash salts. The effort has been to present all the evidence which could be collected, both for and against the use of ground feldspar as a fertilizer. The question is still open, and systematic and long-continued experimentation is the only possible method of obtaining conclusive information on the subject. The evidence so far obtained appears to indicate that under certain conditions and with certain crops feldspar can be made useful if it is ground sufficiently fine. On the other hand, it is highly probable that under other conditions the addition of ground feldspar to the land would be a useless waste of money. At the present stage of the investigation it would be extremely unwise for anyone to attempt to use ground rock, except on an experimental scale that would not entail great financial loss.

The subject must be approached conservatively, with due regard to business economy. Sensationalism and exaggeration invariably do harm. It is extremely unlikely that ground rock will ever entirely displace the use of potash salts, for its availability must inevitably depend upon many modifying conditions, such as the nature of the soil, the amount of moisture present, the character of the other fertilizers used, and the varying root action of different crops. With tobacco the results so far obtained have been encouraging, but it is possible that this plant, which is a voracious feeder, can make use of the potash in fine-ground feldspar to a greater extent than other fast-growing crops, such as potatoes and the cereals, some of which mature in practically sixty days and must therefore find their plant food in a highly available condition.

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